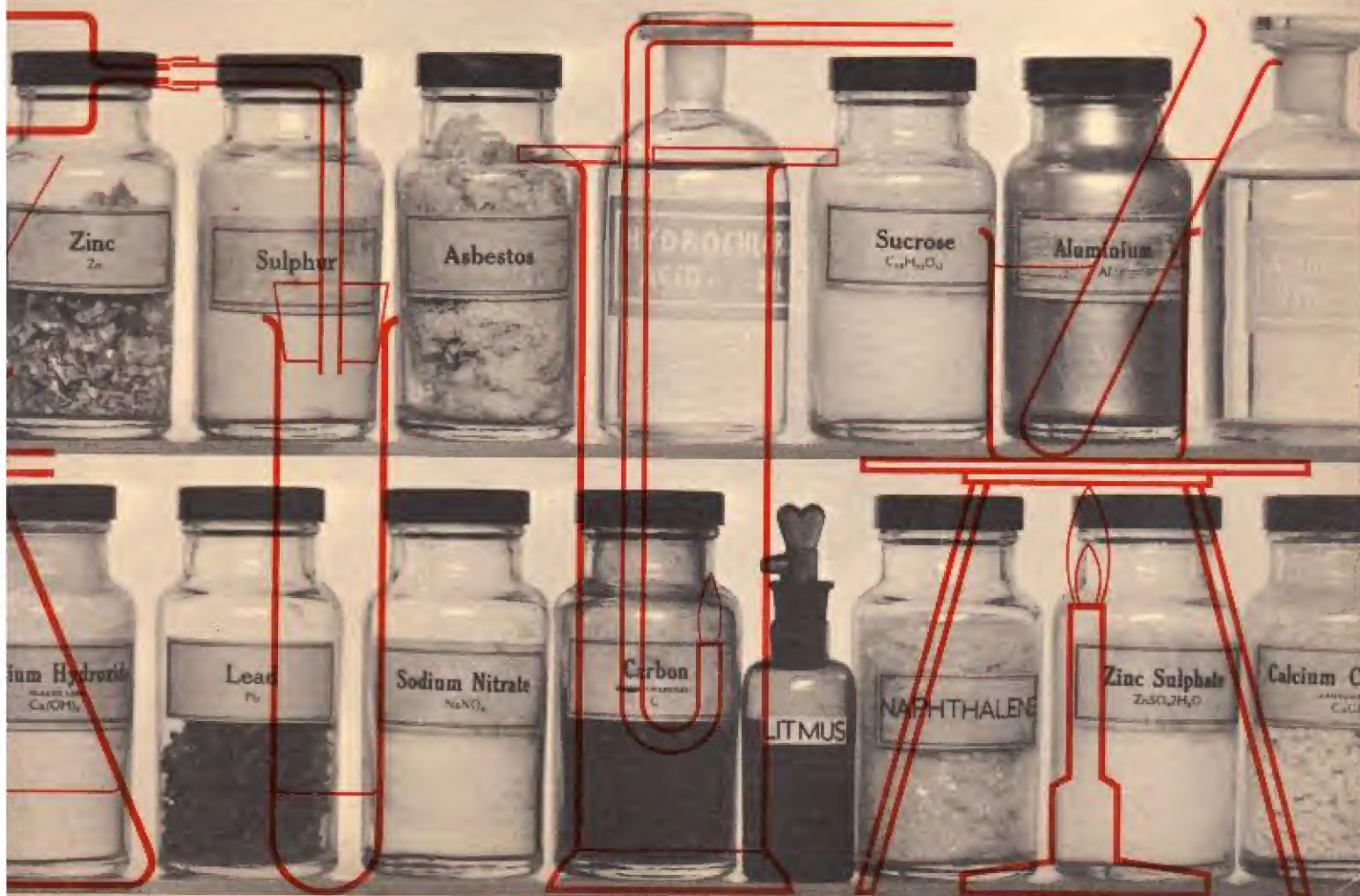
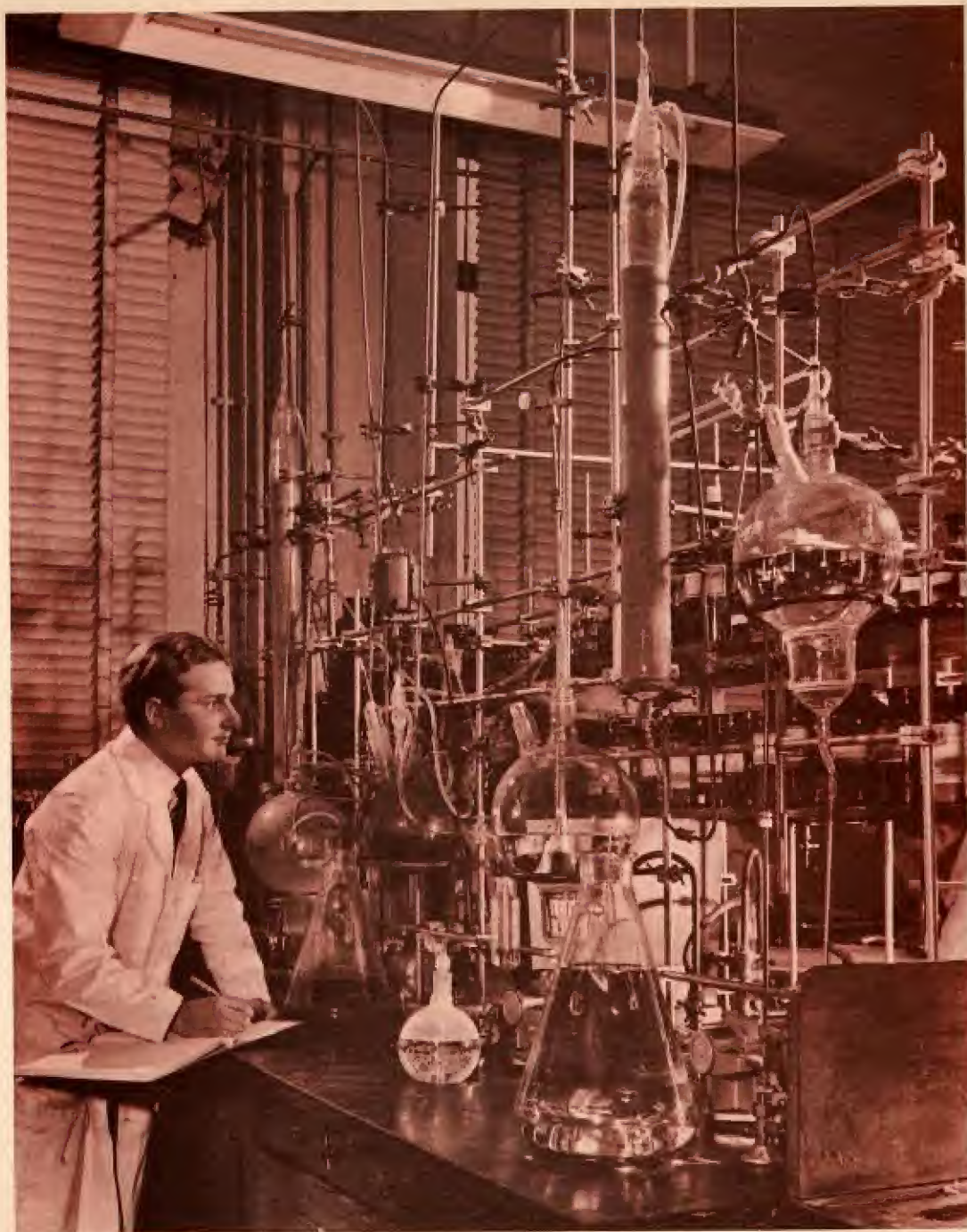


Chemicals from Nature



Why do chemists search for new chemicals? Curiosity and a spirit of adventure drive them. Some chemists, working like detectives, follow up clues until they have found an explanation for some interesting things they have seen. Others try to find new uses for known substances. Still others, knowing that some new substance with specific properties is required, work away until they have made the substance. Here a chemist is making a new plastic.

Shell



part one

Earth, air, and water

Curiosity killed the cat, so we are told. It also made the scientist. Now that you are beginning to study science, it is your job to be inquisitive. That is how science advances. The chemist is inquisitive about one special part of Nature – the behaviour of different substances. He studies all kinds of substances, from iron rust to star dust. He tries to find out what they are made of and how they can be used. He studies changes in substances: the souring of milk and the setting of cement. He attacks substances with heat and with electricity, extracting metals from rocks and salts from sea water. He creates new substances from old: metal alloys that are light and tough, and threads finer than a spider's web yet stronger than steel. With substances like these the chemist is helping to build a new world.

Hundreds and thousands – Look around the chemistry stock-room. Look at the bottles and jars of chemicals.

What do you see? Glassy crystals and brightly coloured powders. Liquids looking like water and liquids sealed in brown glass bottles. Stout metal cylinders containing compressed gases. And there may be a musty smell and perhaps a little dust.

Many chemicals look alike: but the chemists know the difference. They have given each substance a name of its own. Don't be put off by the names. You will soon become familiar with the language and understand the naming system.

But where do all these chemicals come from?

In one way or another they come from the crust of the Earth. Let us start with some metals.

Gold, silver, and copper are sometimes found native, which means that they are not combined with other substances. But most of the copper in the Earth's crust is combined with sulphur in the chemical compound known as copper sulphide. Early man discovered how to make copper metal from this ore. This was the dawn of metallurgy.

Iron, zinc, and tin are also well-known metals. In the crust of the Earth they are commonly combined with oxygen as the compounds called oxides. (You will often have seen iron oxide in the form of rust.) All three metals can be extracted by heating the oxides with carbon, usually in the form of coke.

Lithium, sodium, and potassium are also metals, but less well known. All three are soft, and can be cut with a knife. They can be quite troublesome because they react readily with oxygen in the air and so must be kept under a liquid; but, because they also react with water, they have to be stored in a liquid such as kerosine or xylene.

Mercury (quicksilver) is a liquid metal. You will have seen

it used in thermometers and barometers. In the Earth, mercury occurs as an ore called cinnabar. The metal is obtained by roasting the ore. Mercury is very *dense*, which means that a small quantity weighs a lot. Lifting up a bottle of it can be a strange sensation.

A great many non-metals are also found in the crust of the Earth.

Phosphorus is a non-metal. It is liable to catch fire when exposed to the air and therefore has to be kept under water. Phosphorus used to be extracted from bone ash, but now most of it comes from rocks containing compounds of phosphorus called phosphates.

The non-metal iodine comes from the sea. In the laboratory it can be recognized by the purple-black vapour which it forms. Most iodine used to be obtained from seaweed, which is capable of extracting iodine compounds from sea water. Seaweed is an inconvenient material. Mineral deposits in Chile have become the chief source of iodine.

Carbon is another non-metal. The carbon in the laboratory bottle is probably charcoal, the black powder made by heating wood in the absence of air. But diamond and graphite (the material used to make pencil leads) are also forms of carbon.

The metals and non-metals mentioned so far are simple substances which are known as elements. But most of the laboratory bottles contain compounds – substances formed from the combination of elements. Blue crystals of copper sulphate, green crystals of iron sulphate, the white powder called calcium carbonate, which comes from chalk or limestone – these are only some of them.

Then there are solutions – substances dissolved in water or other liquids. In most laboratories you will find sulphuric, hydrochloric, and nitric acids. The acid bottles labelled 'Concentrated' must be treated with great care because their contents can harm the skin. But even dilute acids should be handled carefully.

Many other solutions are usually to be found. Sodium hydroxide and ammonium hydroxide are alkalis, or substances which neutralize the effect of acids. Litmus, usually kept in a small bottle, is a dye that turns red in acids, and blue in alkalis. It is extracted from some of the lichens which grow on rocks and old trees. The bottle marked ethanol contains an alcohol of the kind present in alcoholic drinks.

Where have all these substances come from?

Order from chaos – All chemicals come from the natural sources, earth, air, and water. These are very mixed-up sources. The chemist first separates the different components; he then takes the purified materials and with them creates new compounds, substances unknown in nature. Plants are living laboratories in which air, water, and simple substances from the soil are turned into complex compounds. The chemist extracts plant products, imitates, and improves them.

To understand the different methods used to get these things, let us look at how some well-known substances are obtained.

Gold – Gold is very dense and will never tarnish. This precious metal is most often obtained from certain hard rocks dug from the earth. After mining, rock containing a small amount of gold is crushed to a powder. When the powder is washed with a stream of water, the lighter material is carried away, leaving the gold behind. From more than fifty tons of rock, miners rarely get as much as a pound of gold.

Another way of extracting gold from its ores depends on the fact that gold sticks to mercury. If mud containing gold is allowed to flow over a copper plate coated with mercury, the gold sticks to the mercury to form a mixture known as an amalgam. A new problem then arises – how to separate the gold and the mercury? Mercury boils away quickly when the amalgam is heated, but the gold does not. (Look up the boiling points of gold and of mercury.) Thus the mercury can be made to boil off as a vapour (vaporize), leaving the gold behind. The mercury vapour can be cooled to produce liquid mercury which is then used over and over again.

Salt – Common salt (known chemically as sodium chloride) is more plentiful than gold: it is found almost everywhere. It occurs in every sea, there are particles of salt in the air, and traces of it can be found on every exposed surface. It is an essential part of human diet and is present in tears and sweat. (The dog that licks your bare legs is not just friendly but also wants the salt on the surface of your skin!)

Naturally-occurring deposits of common salt are known as rock salt and some of the rock salt beds are very large indeed. One deposit in North America covers an area of 100,000 square miles and has an average thickness of 200 feet. The



Trucks carrying ore out of a gold mine. About 50 tons of this ore will probably contain less than 1 lb of gold.



Pouring the extracted gold into a cooling tray.

Making salt in a tropical climate. The salt is made by evaporating sea water in the heat of the sun. Here workmen are collecting the finished product.
Radio Times Hulton Picture Library



salt is mined like coal, and a small quantity of it is mined in this way in Cheshire.

Another commercial source of common salt is sea water. In every ton of sea water, there is 70 lb of dissolved matter, and about 56 lb of that is common salt. In hot countries, sea water in special tanks is allowed to evaporate in the heat of the sun. As the water disappears, the least soluble substances (those which are hardest to dissolve) crystallize first, and the more soluble remain dissolved until the water is nearly all gone. Common salt is moderately soluble. By raking the salt crystals out of the sludge of nearly dried-up brine (salt water), the salt-makers are able to leave out the more soluble salts, obtaining a product which contains about 95 per cent of common salt.

Only a small part of the five million tons of common salt made annually in Britain is used in food and for preserving food. The rest is used in the chemical industry.

Here are some of the substances which are manufactured from salt: chlorine, a green gas used, among other things, to make bleaches and to sterilize swimming pools; sodium hydroxide, used to make soap; and sodium carbonate (known commercially as 'washing soda'). Large quantities of common salt are also used in the manufacture of pottery, in dyeing, in curing leather, and for softening water.

A metal from the sea – Magnesium also comes from the sea. It is a very light metal widely used in making alloys (mixtures of metals), and although sea water does not contain any magnesium *metal*, it does contain the compound magnesium chloride – about $2\frac{1}{2}$ lb of it in a ton of water.

To obtain the metal, the magnesium chloride has first to be got from the sea, and then the magnesium has to be extracted



At this works, magnesium is extracted from sea water. The water is collected in the large tank on the left. From there, it is pumped to the small central tank where it is treated with lime.

Central Office of Information

Scooping out magnesium metal from an electric cell in which magnesium chloride has been decomposed.

Central Office of Information



from the magnesium chloride. But because magnesium chloride is very soluble in water, it cannot be extracted efficiently by evaporating the water and then crystallizing it as with common salt. (Look inside the magnesium chloride bottle in the stock room. Are the contents wet? Magnesium chloride sucks water out of the air.) Magnesium chloride, extracted from brine by a chemical process, is very carefully purified. When a direct electric current is passed through the pure molten magnesium chloride, magnesium metal and chlorine gas are produced. Obtained in this way, magnesium is 99.9 per cent pure. For special purposes it can be further purified by distilling.

Aluminium and electricity – Electricity is used in extracting other substances. The method of using an electric current to separate compounds into their elements is called *electrolysis*. The process is widely used in the chemical industry, for example in the production of hydrogen, chlorine, and sodium, and in the refining (purifying) of gold, silver, and copper. It is also used to extract aluminium – a metal which accounts for 7 per cent of the Earth's crust, but which was as rare as gold until the coming of industrial electrolysis at the end of the nineteenth century. Aluminium occurs naturally as its oxide, *alumina*, and this is very often obtained as the ore called *bauxite*.

The first attempts to obtain aluminium by electrolysis did not succeed because the process only works with materials which are liquid, and alumina will only melt at a high temperature. In 1886 Charles Hall in America and Paul Héroult in France discovered that alumina dissolves in a mineral of low melting point called *cryolite*, a glassy-white mineral, which is found in large quantities in Greenland. This discov-



Liquid air is separated into its different chemicals in this huge distillation column.
British Oxygen Co.

Mining anhydrite in Cumberland with an electro-hydraulic rotary drill. From the anhydrite, sulphuric acid is made.
Crown Copyright

ery led to the extraction of aluminium on a large scale by means of electrolysis. So much electricity must be used that aluminium metal is extracted only where cheap electric current is available. In Britain the largest factories are in Scotland, alongside a hydro-electric power station. Elsewhere, in Canada for example, aluminium factories are also sited near hydro-electric stations.

Sulphur from the earth – Sulphur is a most important substance. It can be seen lying in yellow patches on the slopes of volcanoes. In Texas it is found deep below ground. The American method of extracting sulphur is very ingenious. It makes use of the fact that sulphur melts easily. Hot water is forced down pipes to the beds of sulphur about 500 – 2,500 feet below the ground. As the sulphur melts, it is forced to the surface by compressed air.

Most sulphur is turned into sulphuric acid, which is very widely used in the chemical industry: in dyeing and dye-making; in oil refining, in the plastics industry, and in the making of agricultural fertilizers. Sulphuric acid is so important that when supplies of sulphur from America ran short in 1951, British chemists tried hard to increase the amount of sulphuric acid obtained from materials in the United Kingdom. In West Cumberland there are large deposits of a compound of sulphur called *anhydrite* from which sulphuric acid can be made. The process uses coal which occurs conveniently close by.

Chemicals from the air – We have read about chemicals from the earth, and chemicals from the sea. What about chemicals from the air? Air is a mixture of several gases, but to separate them when they are still gases is difficult. It is easier first to convert the air into a liquid. Just as steam on cooling condenses to water, so air can be condensed into a liquid by compressing it and making it very cold – minus 200° C. The liquid air is then *distilled* to separate the different gases from the mixture.

Distillation is the most convenient way of separating a mixture of different liquids. When the mixture is heated, the liquid substance with the lowest boiling temperature boils off first, then the liquid with the next lowest boiling temperature, and so on. As each liquid boils off, its vapour can be collected and condensed back to a liquid again. The distillation must

be carried out very carefully so that each gas does not mix with a little of another.

From the distillation of liquid air the chemist obtains neon and argon (used in the electric lamp industry), oxygen (for some of the uses of oxygen, see the Background Book, *Burning*), and nitrogen. Much of the nitrogen is used to make ammonia which, in turn, is used to make nitric acid, the third of the common acids which are found in the chemistry laboratory.

To make sulphuric acid requires sulphur – from the earth.

To make nitric acid requires nitrogen – from the air.

To make hydrochloric acid requires chlorine – from sea water. Earth, air, and water.

But to make a great many important chemicals of other kinds, chemists must turn to living things – plants, for example.

Questions

1. What is unusual about the properties of the metals mercury and magnesium?
2. What are some of the things that aluminium is used to make?

part two

Chemicals and plants

A great many chemicals are obtained from plants and some of them are shown in the table on Page 10.

Sugar – The best known chemical that comes from plants is sugar. Although all green plants contain some sugar, only two – sugar cane and sugar beet – are widely used in the production of sugar.

In the extraction of sugar from sugar cane, the cane is first cut into small pieces and then crushed under rollers to extract the juice. The juice is dark grey. As well as a mixture of sugars,

it contains gums, proteins (which are substances in the living cell essential to growth), acids, dirt, and pieces of cane. What a mixture!

First it is filtered to remove the solid impurities. The clean juice is then heated, which causes the dissolved proteins to coagulate (solidify) into lumps. (You will notice this sort of change happen when an egg is boiled, for egg white is a watery protein which coagulates on heating.) Slaked lime is added to neutralize the acids and the mixture is filtered once again. The clear dark juice is then heated to drive off the

In the manufacture of sugar the purified crystals are separated from the sugar juice in giant centrifuges, as shown in the picture. *Tate and Lyle*





Much of the world's supply of sugar cane is grown in the Caribbean. Here a worker is cutting down the ripe cane with a machete. *Paul Popper*

Table showing some of the substances that come from plants

<i>Substance</i>	<i>Source</i>	<i>Some uses</i>
oils and waxes		
Coconut oil	Coconut palm	Margarine, soap, cosmetics
Olive oil	Fruit of olive tree	Margarine, soap, cosmetics
Linseed oil	Flax seeds	Paint, varnish, linoleum
Carnauba wax	Wax palm leaves	High-lustre varnishes, gramophone records, sound film
Turpentine	Long leaf pine	Paint and varnishes
Otto of roses	Damask rose	Perfumery and soap making
Geranium oil	Leaves of some geraniums	Perfumery and soap making
Ylang-ylang	Flowers of ylang-ylang plant	Perfumery and soap making
Camphor	Camphor tree	Celluloid, plastics
drugs and antibiotics		
Quinine	Bark of cinchona tree	Medicine, anti-malaria drug
Cocaine	Coca shrubs	Anaesthetic
Vanilla	Pods of vanilla orchid	Flavouring
Penicillin	Blue green mould	Antibiotic
dyes, etc		
Logwood	Logwood tree	Dyeing silk and cotton
Litmus	A lichen	Test papers
Chlorophyll	Green plants	Soap industry, deodorants
Tannins	Oak bark, acorn cups, chestnut wood	Leather industry, ink manufacture
rubber, etc		
Rubber	Juice of rubber tree	Raw rubber — foam rubber, rubber adhesives. Hardened rubber — motor tyres, shoe soles
Chicle	Fruit of sapodilla tree	Chewing gum, dentistry
sugars, starches, etc		
Sucrose	Sugar cane, sugar beet	Food, chemical industry
Starch	Potatoes, wheat, rice, etc	Food, chemical industry
Agar	Red seaweed	Food
Algin	Brown seaweed	Food, textile industry
Saponin	Soapwort, 'conkers'	Soap substitute, foaming agent

water. Soon sugar crystals begin to form. After cooling, the juice is whirled in a drum (called a centrifuge) rotating at very high speed to separate the raw sugar crystals from the remaining liquid. This liquid is called *molasses*. It is a mixture of sugars that will not crystallize and is used in making sweets and in the manufacture of rum and industrial alcohol.

Raw sugar crystals are brown and contain about 96–98 per cent of sugar. To make white sugar they must be put through a refining process. The crystals are washed with water to remove the film of molasses. After the washing water has drained away, the sugar crystals are dissolved in hot water and strained through charcoal made from bones. Bone charcoal has a very odd property, being able to take up (adsorb) quite large quantities of coloured matter. (Think of an experiment to test this statement.) White sugar, at least 99.9 per cent pure, is crystallized from the now colourless strained solution.

Alcohol galore — Sugar is used in the production of some two thousand substances. Alcohol is the best known of them. The changing of sugar into alcohol is brought about by microscopic plants called yeasts. Thousands of years ago man found that sugary fruit juices exposed to the air would change into intoxicating liquids. Early man also learnt that wine would become sour if it remained exposed to air. These changes are called fermentations. Intoxicating drink is made by fermenting the sugar in the juices with yeast.

Although alcohol is usually associated with drink, it is also a most important industrial chemical. It is used as a *solvent* for dissolving substances, and a starting material from which to make other chemicals. Most of the alcohol used in industry does not come from the fermentation of sugar (which would be expensive), but from the treatment of petroleum gases.

Both petroleum and coal are the remains of living things which existed millions of years ago. You probably know them best as fuels for warming houses or running engines, but they are also valuable starting materials for the manufacture of many hundreds of chemicals.

Plant oils — Olive oil can be obtained by squeezing olives. In a more modern process, the oil is extracted from mashed-up olives by means of special solvents. The solvent must mix with oil but not with water and must evaporate readily. Hexane, a solvent obtained from petroleum, is often used.

A whisky vat in which yeast is bringing about the alcoholic fermentation of a mixture of malt and hot water. *Central Press*



Distilling plant oils from sage leaves. The ground-up leaves, which were picked in Cyprus, are being tipped into the still-pot (top) and the oils are being collected in the flask at the bottom.

Central Office of Information



The solution of oil-in-solvent is heated to evaporate the solvent. The solvent is condensed and used again in the extraction process.

Perfume oils can be extracted with solvents, or by pressing, or by distilling. The solvent process is more expensive than distillation, but gives a finer product. A very old method of making flower perfumes is to press the petals onto plates coated with lard. The petals are changed daily until the lard has become saturated with scented oil. This method is called *enfleurage*.

Colours – Dyes used to be extracted from plants. Nowadays, most of them are made by chemists from petroleum or coal tar. Chemists first copied natural dyes and then they learnt to make dyes without the use of plants. Man-made dyes are more varied than the natural products and more reliable.

Cleopatra did not have the choice of colours, or even of fabrics, that you can find in any multiple store. The sails of her royal barge were dyed with Tyrian purple, extracted from shellfish. This dye could easily be made in the laboratory. It is not a good colour by modern standards. We have faster

and more brilliant purple dyes. Indigo, a blue dye that was once extracted from woad and other plants, is now always prepared in the laboratory. Logwood is perhaps the chief vegetable dye that still comes from the plant.

Rubber – The first toy rubber balls were probably made by American Indians who chewed the milky liquid (latex) obtained from the rubber tree and kneaded the pieces together. Latex is found in many other plants as well as in rubber trees. If you pick a dandelion, you will see latex oozing from the broken stem. But, of all the plants that contain latex, the rubber tree of Brazil yields by far the most.

It is said that Joseph Priestley, who discovered oxygen, gave rubber its name after he had found that a new substance he was studying could be made to rub the marks of a black lead pencil from paper.

But natural rubber is too soft, and is not sufficiently elastic, to be very useful. The rubber industry did not grow to importance until after 1839, when the American Charles Goodyear discovered that heating rubber with sulphur produces a strong and elastic material. Because of this fire-and-brimstone treat-

Preparing a perfume. A few of the plant essences that go into the making of a perfume can be seen in the bottles on the bench.

Central Press





Testing the quality of a
man-made dyestuff.
I.C.I. Dyestuffs Division

Tapping the latex from a
rubber tree.





A giant tyre being removed from a vulcanizing press. In the press the rubber is toughened by heating it with sulphur and is moulded into shape.
Federation of British Rubber and Allied Manufacturers

ment of rubber the process was called 'vulcanization', after Vulcan, the Roman god of fire and the armourer of the gods.

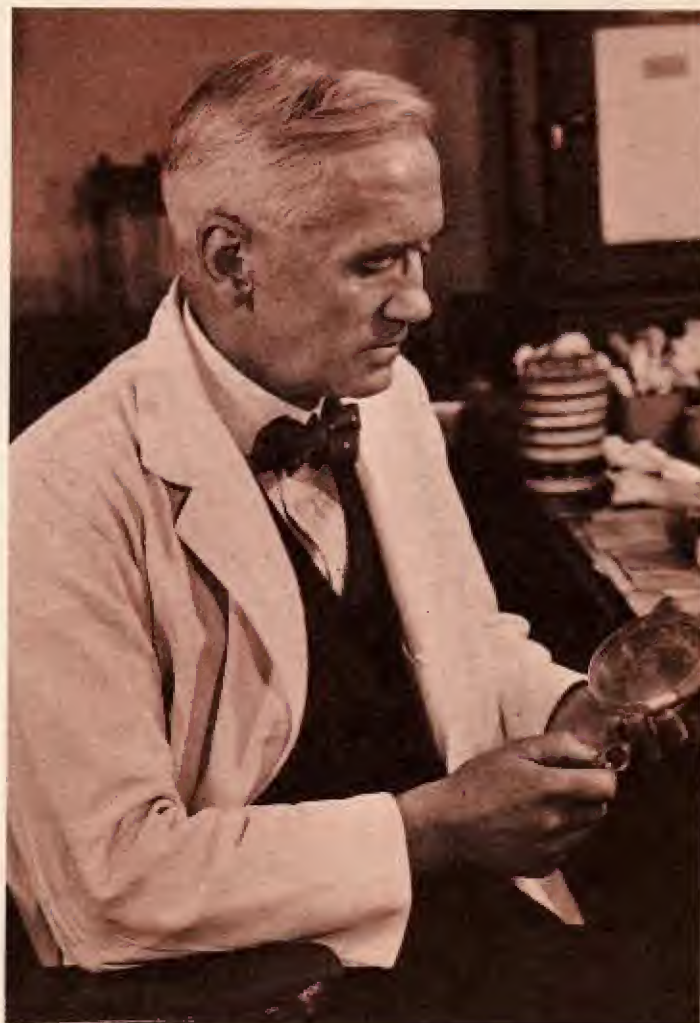
Since Goodyear's discovery, chemists have learnt many tricks in the processing of rubber, and are now able to produce it in a variety of forms – from a spongy foam to a resilient solid. They have gone further and made rubberlike substances artificially from coal or petroleum. These synthetic rubbers have special properties, and can be used for specialized jobs – for example, for making hosepipes to carry oil, where natural rubber would soon deteriorate.

Plant medicines – From very early times, man has used plants to relieve suffering and to cure disease. The search still goes on to discover new substances of medicinal value, to find better ways of extracting those already known and, if possible, to learn enough about the chemistry of substances of value to medicine so that they can be made artificially, and on a commercial scale. For it is often (though not always) a great convenience, and a great saving of money, if the chemicals which come from plants can also be manufactured industrially.

The group of chemicals known as vitamins include several examples of how the chemist has taken over from the plant. Since the eighteenth century, sailors have known that scurvy, a painful and distressing disease, can be prevented or cured by eating fresh fruit. Lime or lemon juice was carried on ships to prevent the disease. In 1927 the Hungarian chemist Szent-Györgyi isolated from fruits and vegetables a substance which was later found to be Vitamin C (ascorbic acid). Methods of making pure crystalline ascorbic acid in the laboratory were discovered, and now it is manufactured in quantity, with sugar as a raw material.

Penicillin is another important medicinal compound ob-

Sir Alexander Fleming, who discovered the antiseptic properties of penicillin, at his laboratory bench. *Today*



tained from plants. Its existence was first suspected in 1929, when Sir Alexander Fleming found that a blue-green mould, very similar to those which sometimes appear on the top of home-made jam, could prevent the growth of certain germs. The chemical responsible was extracted, and doctors were provided with a new and powerful weapon against disease. Hundreds of tons of penicillin are now produced every year. New penicillins and a whole range of antibodies have been discovered and developed.

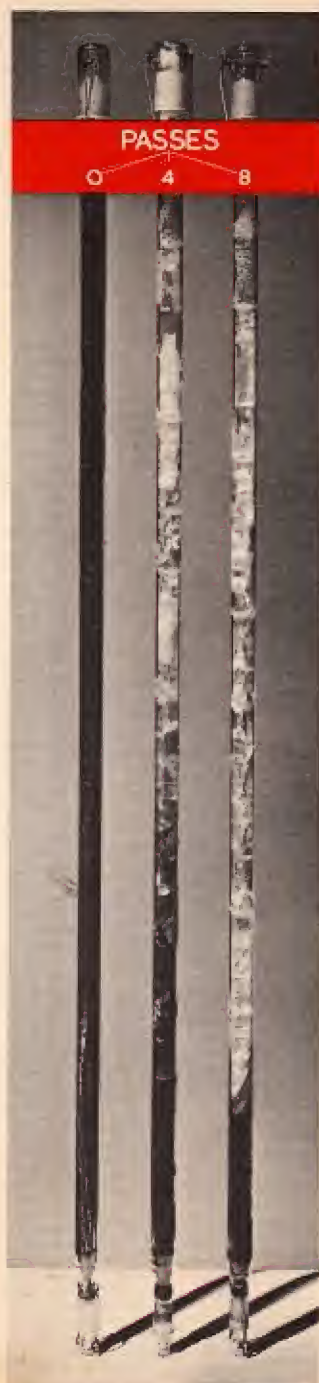
Questions

1. What do plants need to make sugar?
2. How is the alcohol separated from a 'ferment' of sugar and yeast?
3. Make a list of all the separation methods mentioned in this Background Book. Do you know any others?

Laboratory chemicals - The chemicals in the bottles on your bench or in the chemistry stock-room have been made or extracted from more complex raw materials. They have usually been carefully purified, so that impurities should not affect their chemical behaviour. This Background Book has shown you some of the ways in which all this is done. When you are working with chemicals in the laboratory, sometimes stop to remember how they have been obtained. Or, if you do not know, try to find out.



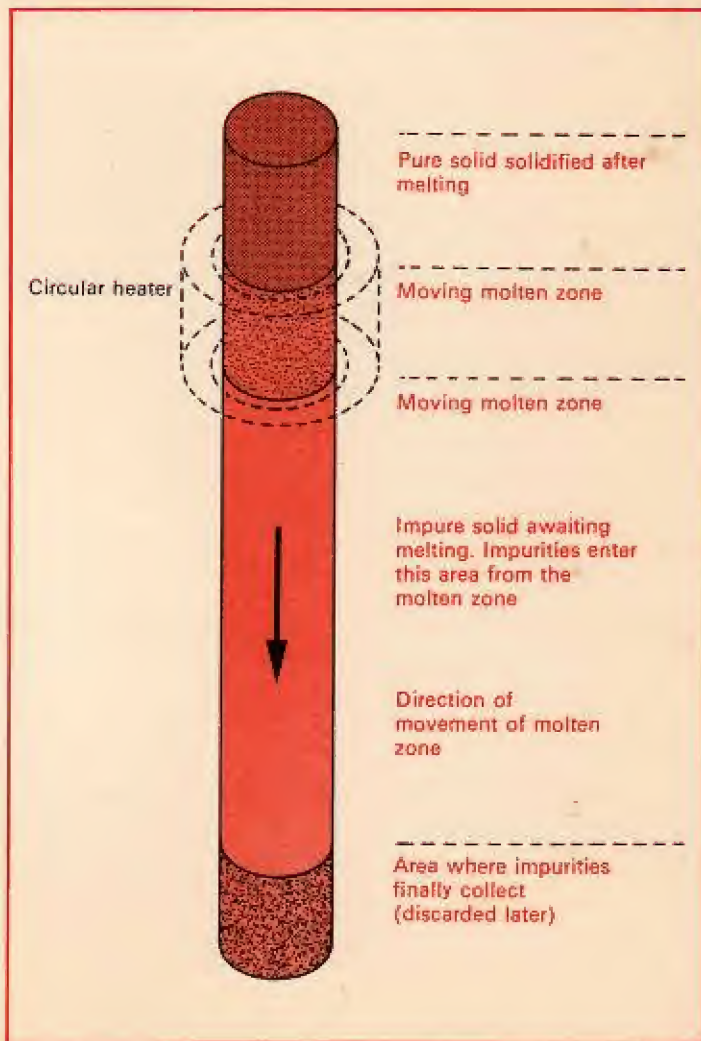
Two ways of purifying solids
a. Sublimation – A few solids on heating vaporize before they melt. When the vapour is cooled, the solid re-forms. This process is called sublimation. Purifying solids by sublimation is similar to purifying liquids by distillation. Iodine is a solid which sublimates. In the top lefthand photograph raw iodine is vaporized in the brick furnaces. It is deposited on the inner walls of a series of earthenware pipes lying horizontally behind the furnaces. The bottom lefthand photograph shows the pure crystalline iodine inside a pipe ready for collection.
Chilean Iodine Educational Bureau



b. Zone refining is a new process used for purifying solids: the very pure metals needed to make transistors for example. A narrow circular heater moves down a column of the solid, making a hot molten zone as it passes. The hot zone attracts the impurities in the solid which travel down with it and concentrate at the bottom, as shown in the diagram. As you can see from

the photograph the solid becomes purer every time the zone is passed through the column. The tube on the left has not been refined, the centre one has been refined four times, and the right-hand one eight times.

National Physical Laboratory



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